Endovascular aneurysm repair for ruptured abdominal aortic aneurysm: The Albany Vascular Group approach

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Improvements in endovascular technology and techniques have allowed us to treat patients in ways we never thought possible. Today, endovascular treatment of ruptured abdominal aortic aneurysms is associated with markedly decreased morbidity and mortality compared with the open surgical approach, yet there are several fundamental obstacles in our ability to offer these endovascular techniques to most patients with ruptured aneurysms. This article will focus on the technical aspects of endovascular aneurysm repair for rupture, with particular attention to developing a standardized multidisciplinary approach that will help vascular surgeons deal with not just the technical aspects of these procedures but also address some of the challenges, including the availability of preoperative computed tomography, the choice of anesthesia, the percutaneous vs femoral cutdown approach, use of aortic occlusion balloons, need for bifurcated vs aortouniiliac stent grafts, need for adjunctive procedures, diagnosis and treatment of abdominal compartment syndrome, and conversion to open surgical repair. (J Vasc Surg 2010;52:1706-12.)

The evolution of endovascular aneurysm repair (EVAR) has led to improvements in our ability to treat abdominal aortic aneurysms (AAA) in elective as well as in emergent circumstances when patients present with rupture.[1-3] The implications of improvements in our technical ability to offer EVAR to patients presenting emergently with AAA rupture are significant: to date, no other therapy has offered such a survival advantage to these high-risk patients presenting with AAA rupture. When considering these endovascular techniques for treating ruptured AAA, one has to prepare for the challenges of streamlining patient care from the emergency room (ER) to the operating room (OR) and the subsequent endovascular procedure that often requires a multidisciplinary approach and a change in paradigm and local cultures. This article will focus on a comprehensive and standardized technical approach for treating ruptured AAA by endovascular means that can maximize our ability to offer this treatment of ruptured AAA to most patients.

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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a competition of interest.
0741-5214/$36.00

doi:10.1016/j.jvs.2010.06.103

UNDERSTANDING THE LIMITATIONS OF EVAR FOR RUPTURE

There are several reasons for our failure to adopt endovascular technology as the first-line therapy for patients with aneurysm rupture:

1. availability of preoperative computed tomography (CT) scans in *all* patients with ruptured AAA,
2. availability of dedicated operating room staff equipped to perform emergent EVAR at all times,
3. availability of off-the-shelf stent grafts, and
4. inadequate experience and ability in managing unexpected endovascular issues during emergency repair.

GETTING STARTED

Although one or more of these limitations might have some impact on a vascular surgeon's ability to incorporate endovascular techniques in managing patients with ruptured AAA, in my opinion, the fundamentals for success begin from establishing a standardized approach that is multidisciplinary and inclusive of the ER physicians, the anesthesiologists, the OR nurses, technologists, and the vascular surgeons.

To get started, the surgeon/interventionist should:

1. become comfortable performing EVAR under elective circumstances,
2. obtain an inventory of standard equipment (wires, catheters, sheaths, balloons, particularly the compliant aortic occlusion balloons, and fluoroscopic equipment) that is needed to perform elective EVAR safely,
3. pick and chose the stent grafts that he or she is most comfortable using, and acquire select stent graft sizes to

match the largest aortic neck diameter and the shortest aneurysm length, with a variety of iliac extensions to treat most if not all AAAs,
4. become comfortable with adjunctive procedures such as iliac interventions that might be needed to facilitate access, use of compliant aortic occlusion balloon, and placement of Palmaz (Cordis, Miami Lakes, Fla) stents at the aortic neck, and
5. only treat hemodynamically stable patients who have undergone CT scans.

With increasing experience, one can easily modify his or her inclusion and exclusion criteria for EVAR of ruptured AAA that can even accommodate hemodynamically unstable patients.

EVAR FOR RUPTURED AAA: A STANDARDIZED APPROACH

Treatment of ruptured AAA patients involves a multidisciplinary approach that includes ER staff, anesthesiologists, OR staff, radiology technologists, and vascular surgeons/interventionists, and therefore requires a standardized approach that engages all parties and facilitates a seamless transition of the patient from the ER to the OR for EVAR. Although the standardization of any approach will vary from hospital to hospital, the fundamentals are simple: success depends on the early diagnosis of ruptured AAA, the ability to have an expeditious CT scan to evaluate the aortoiliac morphology, and quick transition of the patient from the ER to an OR that is equipped to perform endovascular as well as open surgical repair under these emergent circumstances.

In 2002 we developed a standardized approach at the Vascular Institute for Health and Disease in Albany[4] that has enabled us to use an endovascular approach as the first-line therapy for all patients that present with ruptured AAA, and this has resulted in a significant improvement in patient survival (Fig 1). The fundamentals of the protocol include a heightened awareness among the ER staff to suspect the diagnosis of ruptured AAA and notify the on-call vascular surgeon and the OR staff. Hemodynamically stable patients undergo an expeditious CT scan in the ER and are subsequently transferred to the OR, and hemodynamically unstable patients are directly transferred to the OR without a preoperative CT scan for an endovascular-first approach and conversion to open surgical repair as needed.

OR SETUP

Because not all patients with ruptured AAA can undergo endovascular repair, all OR and hybrid endovascular/OR suites should be set up to facilitate endovascular as well as open surgical repair. Depending on the size of the room and the fluoroscopic equipment, which can be fixed or portable with viewing screens and power injectors, one has to customize the layout of the OR suite that is conducive for endovascular and open surgical repair. We have found it best to set up the room for endovascular repair with standard needles, wires, catheters, and sheaths open on a sterile

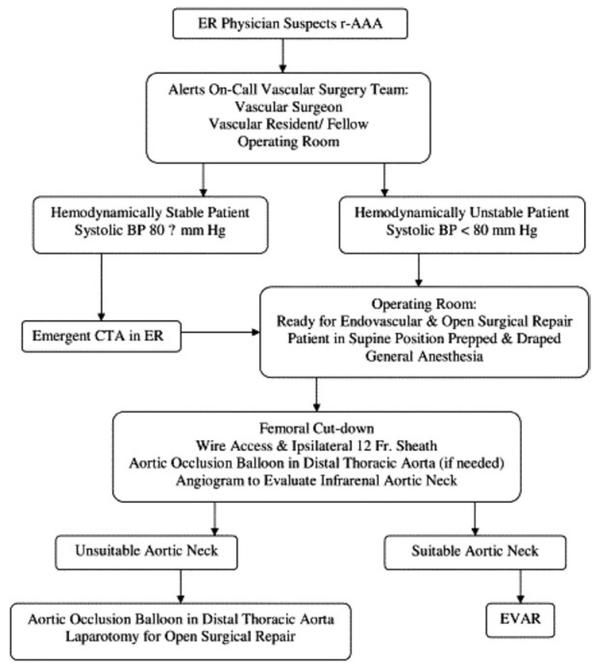

Fig 1. Albany Vascular Group standardized protocol for endovascular aneurysm repair (*EVAR*) of ruptured abdominal aortic aneurysms (*r-AAA*). *BP,* Blood pressure; *CTA,* computed tomography angiography; *ER,* emergency room.

table, have the surgical instruments in the room if needed, situate the patient on the OR table, and as the anesthesiology team prepares the patient, set up the fluoroscopic equipment and supplies.

THE FUNDAMENTAL TECHNIQUES

Adequate resuscitation of patients with ruptured AAA is vital to a successful outcome. As long as the patients maintain a measurable blood pressure, the techniques of hypotensive hemostasis by limiting the resuscitation to maintain a detectable blood pressure can help minimize ongoing hemorrhage. The patient is placed supine and is prepared and draped.

Through a femoral artery cutdown, ipsilateral access is obtained using a needle, floppy guidewire, and a guiding catheter. The floppy guidewire is exchanged for a super-stiff wire that can be used to place a large sheath (12F to 14F × 45-cm length) in the ipsilateral femoral artery, and the sheath is advanced up to the juxtarenal abdominal aorta so it is ready to be used to deliver and support the aortic occlusion balloon, if needed. A compliant occlusion balloon should always be available in these procedures. In hemodynamically unstable patients, the occlusion balloon is advanced through the ipsilateral sheath over the super-stiff wire into the supraceliac abdominal aorta under fluoroscopic guidance, and the balloon is inflated as needed. In our experience of >100 EVARs for ruptured AAA, the aortic occlusion balloon is needed in <25% of cases. Access is subsequently obtained from the contralateral femoral artery cutdown in similar fashion, and a marker flush-catheter is advanced to the juxtarenal aorta for an arteriogram.

The placement of the stent graft main body is planned based on the aortoiliac morphology that is best suited for EVAR. Unless prohibitive, *in hemodynamically stable patients,* after the initial arteriogram, the aortic occlusion balloon is removed from the initial ipsilateral side, and the stent graft main body is advanced under fluoroscopic guidance, which limits the number of catheter exchanges. *In hemodynamically unstable patients* who require inflation of the aortic occlusion balloon, the marker flush-catheter is exchanged for the stent graft main body, which is delivered up to the renal arteries. An arteriogram is done through the sheath that is used to support the aortic occlusion balloon, the tip of the stent graft main body is aligned with the lowermost renal artery, the occlusion balloon is subsequently deflated and withdrawn back with the delivery sheath into the AAA, and the stent graft main body is deployed.

The rest of the EVAR procedure is performed similarly in elective circumstances: (1) the tip of the stent graft main body is aligned with the lowermost renal artery, (2) the contralateral gate is aligned to facilitate expeditious gate-cannulation, and (3) the ipsilateral and contralateral iliac extensions planned and deployed as needed.

There are several important technical aspects that merit discussion, including:

- availability of preoperative CT scan,
- choice of anesthesia and percutaneous vs femoral cutdown approach,
- aortic occlusion balloons,
- bifurcated vs aortouniiliac (AUI) stent grafts,
- adjunctive procedures,
- assessing for abdominal compartment syndrome (ACS), and
- conversion to open surgical repair.

Availability of preoperative CT scan. The hemodynamic status of the ruptured AAA patient generally dictates the need for a preoperative CT scan, and although a preoperative CT is not considered a necessity when planning for an emergent open surgical repair, most would agree that when planning an emergent EVAR, we would like to have a CT scan for evaluating the feasibility of EVAR as well as for stent graft sizing.

So the question is whether one has the time to get an emergent CT scan before EVAR, and if not, are other tools available that might help us manage these hemodynamically unstable patients by endovascular means? Lloyd et al[5] published data on a time-to-death study in patients with ruptured AAA who did not undergo treatment. They found that 49 of 56 patients (88%) with the diagnosis of ruptured AAA died >2 hours after admission. The median interval from the onset of symptoms to admission to the hospital was 2.5 hours, and the interval between hospital admission with the diagnosis of ruptured AAA and death was 10.5 hours. These data would suggest that most patients with ruptured AAA have the time to undergo an emergent CT scan, particularly if there is an established protocol that facilitates early diagnosis and transfer of the patient from the ER to the OR.

The obvious question that remains is, how often are ruptured AAAs suitable for EVAR? We recently have tried to answer just that by evaluating CT scans of 50 consecutive patients who presented with ruptured AAA and had an available CT scan. The endovascular anatomic inclusion criteria were slightly modified from the standard indications for use defined by each of the U.S. Food and Drug Administration-approved devices and focused on feasibility of EVAR for ruptured AAA. This included aortic neck length ≥10 mm, aortic neck diameter ≤32 mm, aortic neck angulation ≤75°, and bilateral iliac artery diameter ≤5 mm. With these criteria, our findings indicated that 80% of ruptured AAA patients could be considered anatomically suitable for EVAR, and this is comparable to our clinical findings of treating >100 ruptured AAA patients by endovascular means.

Choice of anesthesia and approach. Depending on one's comfort level and the logistics, EVAR for AAA rupture can be performed under local anesthesia through a percutaneous approach or with general anesthesia and femoral artery cutdown. The potential benefits of local anesthesia and the percutaneous approach is that it might avoid the loss of sympathetic tone in compromised ruptured AAA patients.[6] Percutaneous techniques have several limitations: the currently available stent grafts are delivered through large sheath sizes (18F to 24F), and one has to be comfortable with obtaining percutaneous access and using closure devices in patients who might be hemodynamically unstable with difficult to palpate femoral pulses. One also needs to be comfortable with preclose techniques using ProStar XL and Perclose ProGlide Suture-Mediated Closure System (Abbott Vascular, Santa Clara, Calif).[7]

In hemodynamically stable patients, particularly in the hands of experienced operators, these percutaneous procedures are quite feasible. However, our standard approach has been to perform EVAR for rupture under general anesthesia with femoral artery cutdown. We have found that femoral access by cutdown can be accomplished within minutes, and this approach is easier to standardize than the percutaneous approach.

We have reserved the percutaneous approach for EVAR of ruptured AAA in select patients who are considered to be hemodynamically unstable, are conscious, and can cooperate with the anesthesiologist and the vascular surgeon/interventionalist. In these patients, we prefer to access the femoral artery percutaneously *without* a closure device, advance an appropriately sized sheath (18F to 22F) as needed, and complete the EVAR. The femoral sheathes are removed through the femoral artery cutdown at the conclusion of the procedure, and direct femoral artery repair is completed. Of course, the preclose technique for totally percutaneous EVAR for ruptured aneurysms is most certainly used. This approach needs to be individualized according to the patient's hemodynamic status.

Aortic occlusion balloon. The appropriate use of aortic occlusion balloons in hemodynamically unstable pa-

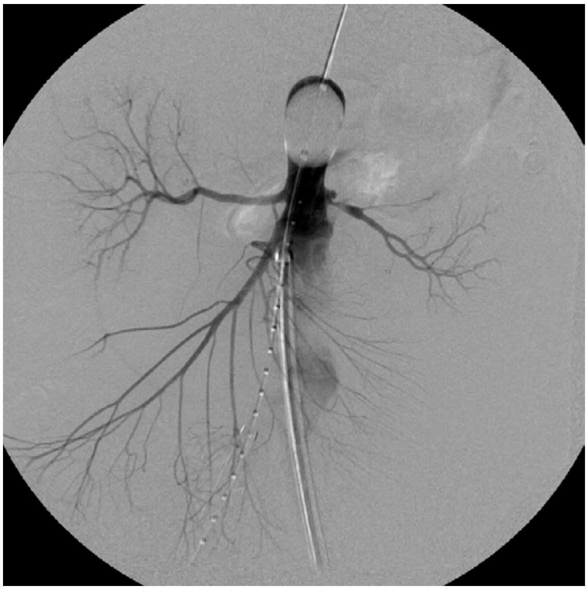

Fig 2. The sheath supporting the aortic occlusion balloon should be advanced and supported fully into the aortic neck to prevent downward displacement and prolapse of the occlusion balloon into the abdominal aortic aneurysm.

tients is vital to the success of EVAR in these emergent circumstances. We prefer to use the femoral approach for placing aortic occlusion balloons and have found this has several advantages: (1) it allows the anesthesia team to have access to both upper extremities for arterial and venous access; (2) patients who require the aortic occlusion balloon are often hypotensive, and in these patients, percutaneous brachial access can be difficult and more time consuming than femoral cutdown; and (3) the currently available aortic occlusion balloons require at least a 12F sheath, which requires a brachial artery cutdown and repair, and stiff wires, and catheters across the aortic arch without prior imaging under emergent circumstances might lead to other arterial injuries or embolization causing a stroke.

There are several important points to consider during procedures that require inflation of the aortic occlusion balloons to maintain hemodynamic stability. To facilitate stabilization of the balloon catheter during inflation and maintain aortic occlusion at the suprarenal and supraceliac level, the sheath supporting the balloon should be advanced and supported fully into the aortic neck before inflation of the occlusion balloon, because this will prevent downward displacement and prolapse of the occlusion balloon into the AAA (Fig 2). Inability to fully engage the sheath into the aortic neck due to the presence of significant aortoiliac stenosis, calcifications, or tortuosity might result in downward displacement of the inflated occlusion balloon. Forward traction on the inflated balloon catheter is often required to maintain adequate position at the suprarenal and supraceliac aorta (Fig 3).

If inflation of the aortic balloon is required to maintain a viable blood pressure, then the rest of the endovascular repair should be conducted expeditiously to limit the time of aortic occlusion and further limit the development of complications of ongoing bleeding, such as abdominal compartment syndrome and multiorgan system failure. During the procedure, just before deployment of the stent graft main body, the aortic occlusion balloon should be deflated from the suprarenal level and withdrawn. The stent graft main body is then deployed, which will avoid trapping the compliant aortic occlusion balloon between the aortic neck and the stent graft. This temporary deflation of the aortic occlusion balloon rarely results in hemodynamic collapse and usually is of little consequence.

In hemodynamically unstable patients, the occlusion balloon can be redirected into the aortic neck from the side ipsilateral to the stent graft main body and reinflated at the infrarenal aortic neck within the stent graft main body. This allows for aortic occlusion and does not interfere with the rest of the endovascular procedure (Fig 4, *A-E*).

Currently, four different compliant occlusion balloons are readily available, with subtle differences (Table). Occlusion balloons are composed of compliant materials, such as polyurethane, latex, or silicone, and have low burst pressures of <5 atm. Their primary function is not angioplasty, but molding to their surroundings with gentle inflation. They function in the capacity of obtaining proximal aortic occlusion during EVAR for ruptured AAA and should be in the armamentarium of all vascular specialists treating AAA.

Bifurcated vs AUI stent grafts for ruptured AAA. Although the decision to use a particular stent graft type and size is determined by the patient's aortoiliac morphology, among the factors that predispose our decisions to use bifurcated vs AUI stent grafts in these aortic emergencies are (1) the inability to expeditiously access the contralateral gate, and (2) the inability to access the contralateral iliac artery due to significant occlusive disease or tortuosity. When bifurcated stent grafts are used, even in patients who maintain adequate hemodynamic status, there is the potential for ongoing bleeding until adequate proximal and distal fixation in the aortic neck and iliac arteries is obtained. During the procedure, if rapid gate cannulation is not obtained, particularly in hemodynamically unstable patients, the bifurcated stent grafts should be converted to AUI devices by using stent grafts such as the Renu device (Cook Inc, Bloomington, Ind) or by placing aortic cuffs or a second stent graft main body across the stent graft flow-divider to divert all blood flow to the ipsilateral iliac artery. This does require subsequent interruption of flow from the contralateral common iliac artery into the AAA through a stent graft occluder and a femoral-femoral bypass.

In our experience of >100 EVAR for ruptured AAA, approximately 15% have required emergent conversion of bifurcated stent grafts into AUI devices. To facilitate contralateral gate cannulation during EVAR, we routinely cross the stent graft limbs to align them with the contralateral sheath, which is usually crossed and anterior to the ipsilateral sheath. With this approach, gate cannulation can usually be achieved within minutes.

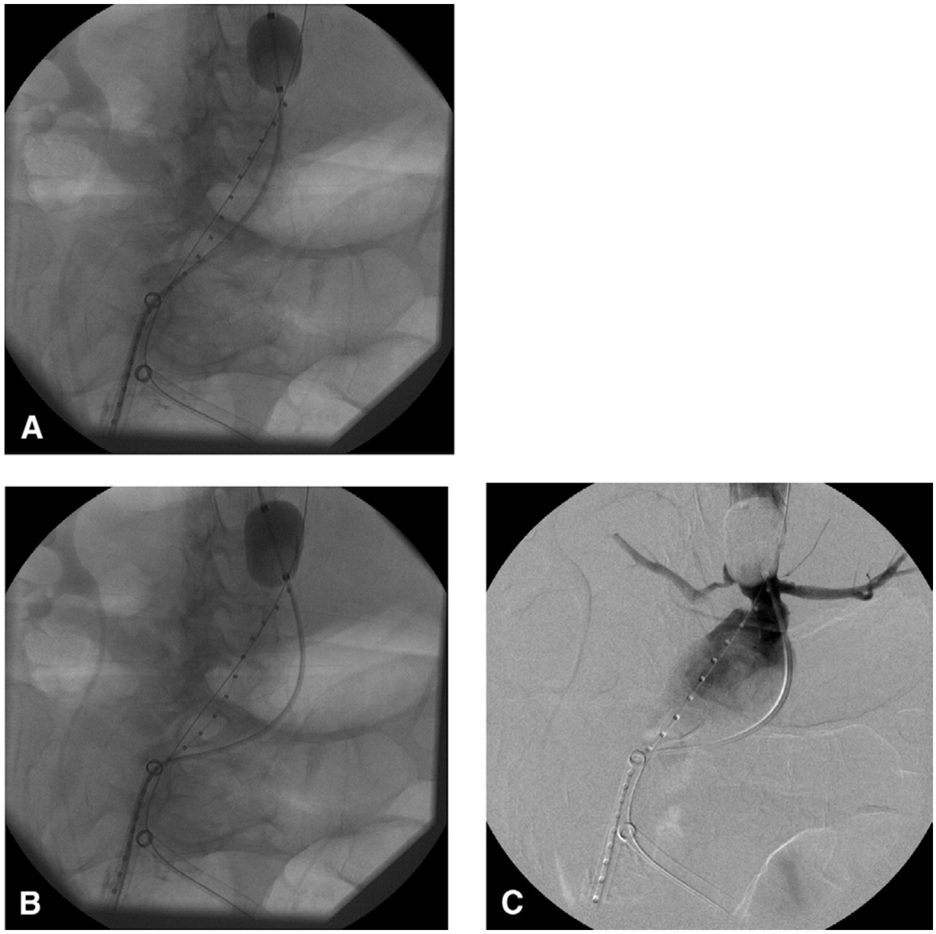

Fig 3. Inability to fully engage the sheath into the aortic neck due to the presence of significant aortoiliac stenosis, calcifications, or tortuosity might result in downward displacement of the inflated occlusion balloon. This often requires forward traction on the inflated balloon catheter to maintain adequate position at the suprarenal/supraceliac aorta (**A, B, C**).

Adjunctive procedures. Owing to the obvious emergent nature of ruptured AAA, preoperative planning can be less than ideal, which can lead to the need for additional unexpected adjunctive procedures. To discuss all adjunctive procedures that might be needed during EVAR for ruptured AAA is beyond the scope this article; however, the use of Palmaz stents at the aortic neck for treatment of type I endoleaks is a technique that should be in one's armamentarium.[8] Our standard approach includes the following:

1. A Palmaz 4910 stent is hand-crimped and centered onto a 20- to 25-mm noncompliant Maxi-LD balloon (Cordis).
2. Both ends of the Maxi-LD balloon with the Palmaz stent are slightly inflated to avoid "watermelon seed" displacement of the Palmaz stent during deployment,
3. A 16F to 18F delivery sheath is advanced into the straight and nontortuous main body of the stent graft.
4. The Palmaz stent is loaded onto the balloon, delivered to the juxtarenal aorta, aligned for deployment partially in the stent graft main body and the native aortic neck, and deployed under fluoroscopic guidance.
5. The Maxi-LD balloon is exchanged for a compliant aortic occlusion balloon, described earlier, and the Palmaz stent is molded to anchor the stent graft to the aortic wall.

Assessing for ACS. With the increasing use of endovascular techniques for treating ruptured AAA, there is an increased recognition of new complications, such as ACS.[9] The pathophysiology of ACS after EVAR for ruptured AAA is multifactorial: (1) the retroperitoneal hematoma is a space-occupying lesion and a significant factor contributing to intra-abdominal hypertension, (2) ongoing bleeding from lumbar and inferior mesenteric arteries into the disrupted aneurysm sac in the setting of severe coagulopathy might be a contributing factor, and (3) the shock state associated with ruptured AAA is associated with alterations in microvascular permeability that can lead to visceral and soft tissue edema.

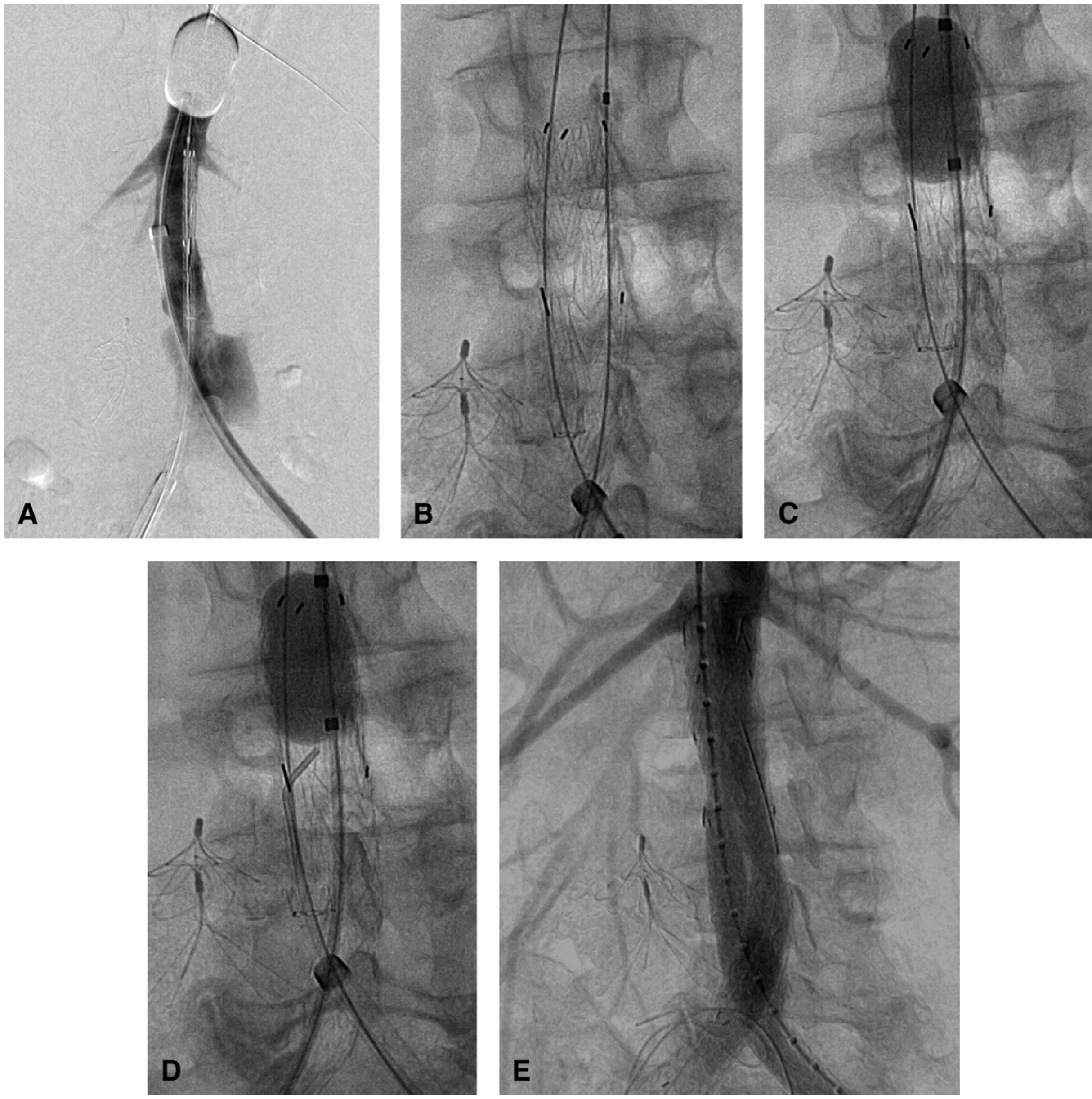

Fig 4. Managing the aortic occlusion balloon during stent graft deployment. **A,** The inflated suprarenal aortic occlusion balloon is advanced through the left femoral approach, the stent graft main body is advanced through the right femoral approach, and the arteriogram is done through the left femoral sheath supporting the occlusion balloon. **B,** The aortic occlusion balloon is deflated and retracted back from the aortic neck, and the stent graft main body is subsequently deployed. This avoids trapping of the compliant aortic occlusion balloon between the aortic neck and the stent graft. **C,** In hemodynamically unstable patients, the occlusion balloon can be redirected into the aortic neck from the side ipsilateral to the stent graft main body and reinflated at the infrarenal aortic neck within the stent graft main body before contralateral gate cannulation. **D,** After the occlusion balloon is reinflated in the stent graft main body in hemodynamically unstable patients, the contralateral stent graft gate can be cannulated and contralateral stent graft extensions are placed as needed. **E,** After contralateral iliac extension and ruptured abdominal aortic aneurysm exclusion, the occlusion balloon can be removed, as shown in the completion arteriogram.

Most published data would suggest that the incidence of ACS after EVAR for ruptured AAA varies and probably depends on the hemodynamic status of the patients being treated. In our own series of EVAR for ruptured AAA in hemodynamically stable and unstable patients, the incidence of ACS was 18%, and several variables were identified as significantly contributing factors. These include (1) use of aortic occlusion balloon, (2) need for massive blood

Table. Properties of compliant aortic occlusion balloons

Occlusion balloon	*Sheath size*	*Catheter length*	*Max balloon diameter*
Reliant (Medtronic Ave)	12F	100 cm	46 mm
Coda (Cook Inc)	14F	100-120 cm	32, 40 mm
Equalizer (Boston Scientific Corp)	14-16F	65 cm, 110 cm	20, 27, 33, 40 mm
Q-50 (W. L. Gore)	12F	65 cm	10-50 mm

transfusions (mean 8 units of packed red blood cells), and (3) coagulopathy with elevated activated partial thromboplastin time at completion of the case. In our experience, patients with ACS had a significantly increased mortality (67%) compared with those without ACS (10%). Our protocol for the endovascular treatment of ruptured AAA has evolved as a result of these observations.

We avoid systemic heparinization, which was used earlier in our experience during EVAR for rupture, and coagulation studies are aggressively corrected during the perioperative period to help limit the ongoing bleeding from collateral vessels. Furthermore, bladder pressures are recorded hourly during the procedure and also postoperatively. If bladder pressures are increased, regardless of the presence of other associated factors, we emphatically recommend that patients undergo decompression laparotomy. However, the question is how many factors need to be present in the absence of increased bladder pressures to accurately predict ACS. In our clinical practice, regardless of the presence of increased bladder pressures, if patients have more than one risk factor for developing ACS (aortic occlusion balloon, massive blood transfusion, or coagulopathy), have abdominal distention, and manifest signs of end-organ dysfunction, they undergo on-table laparotomy. We believe that these measures might help identify and treat ACS and decrease the associated morbidity and mortality.

Conversion to open surgical repair. Regardless of all the improvements in endovascular techniques, on-table conversion to open surgical repair is sometimes needed, and this approach should be in the armamentarium of all surgeons/interventionalists involved in treating ruptured AAA patients. A comprehensive discussion of open surgical repair is beyond the scope of this article, but a few key points need to be mentioned here.

When on-table surgical conversion is needed, the use of aortic occlusion balloon can be extremely valuable in maintaining hemodynamic stability. The techniques of aortic occlusion balloon were discussed in an earlier section. In addition, it is crucial during the time of laparotomy and open surgical conversion to maintain the position of the aortic occlusion balloon and its delivery sheath. Failure to do so might result in aortic occlusion balloon prolapse into the AAA and loss of aortic occlusion. If open surgical conversion is needed after stent graft deployment, the exact approach should be tailored to the type of stent graft and the type of proximal and distal fixation, including suprarenal vs infrarenal stents and barbs.

CONCLUSIONS

Endovascular repair of ruptured AAA is evolving and offers the potential for improved patient survival. Unlike elective EVAR, the time for preoperative planning during emergent EVAR is limited, and the preoperative imaging is often less than ideal. One often has to get creative and use more of a problem-solving approach to address challenging issues that might arise during these emergent circumstances. A standardized multidisciplinary approach can be instrumental in organizing pathways that can accommodate individual practices and hospital infrastructure and can facilitate a seamless transition of these often hemodynamically unstable patients from the time of diagnosis to successful EVAR. There are several important technical aspects, including the choice of anesthesia, percutaneous vs femoral cutdown approach, use of aortic occlusion balloons, use of bifurcated vs AUI stent grafts, and adjunctive procedures that need to be well understood as one embarks on performing these procedures. Good luck!

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Submitted Apr 22, 2010; accepted Jun 9, 2010.